

MAS352/452/6052 – Formula Sheet – Part One

Where not explicitly specified, the notation used matches that within the typed lecture notes.

Modes of convergence

- $X_n \xrightarrow{d} X \Leftrightarrow \lim_{n \rightarrow \infty} \mathbb{P}[X_n \leq x] = \mathbb{P}[X \leq x]$ whenever $\mathbb{P}[X \leq x]$ is continuous at $x \in \mathbb{R}$.
- $X_n \xrightarrow{\mathbb{P}} X \Leftrightarrow \lim_{n \rightarrow \infty} \mathbb{P}[|X_n - X| > a] = 0$ for every $a > 0$.
- $X_n \xrightarrow{a.s.} X \Leftrightarrow \mathbb{P}[X_n \rightarrow X \text{ as } n \rightarrow \infty] = 1$.
- $X_n \xrightarrow{L^p} X \Leftrightarrow \mathbb{E}[|X_n - X|^p] \rightarrow 0$ as $n \rightarrow \infty$.

The binomial model and the one-period model

The binomial model is parametrized by the deterministic constants r (discrete interest rate), p_u and p_d (probabilities of stock price increase/decrease), u and d (factors of stock price increase/decrease), and s (initial stock price).

The value of x in cash, held at time t , will become $x(1+r)$ at time $t+1$.

The value of a unit of stock S_t , at time t , satisfies $S_{t+1} = Z_t S_t$, where $\mathbb{P}[Z_t = u] = p_u$ and $\mathbb{P}[Z_t = d] = p_d$, with initial value $S_0 = s$.

When $d < 1+r < u$, the risk-neutral probabilities are given by

$$q_u = \frac{(1+r) - d}{u - d}, \quad q_d = \frac{u - (1+r)}{u - d}.$$

The binomial model has discrete time $t = 0, 1, 2, \dots, T$. The case $T = 1$ is known as the one-period model.

Stirling's Approximation

It holds that $n! \sim \sqrt{2\pi n} \left(\frac{n}{e}\right)^n$.

Conditions for the optional stopping theorem (MAS452/6052 only)

The optional stopping theorem, for a martingale M_n and a stopping time T , holds if any one of the following conditions is fulfilled:

- (a) T is bounded.
- (b) $\mathbb{P}[T < \infty] = 1$ and there exists $c \in \mathbb{R}$ such that $|M_n| \leq c$ for all n .
- (c) $\mathbb{E}[T] < \infty$ and there exists $c \in \mathbb{R}$ such that $|M_n - M_{n-1}| \leq c$ for all n .

MAS352/452/6052 – Formula Sheet – Part Two

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The normal distribution

$Z \sim N(\mu, \sigma^2)$ has probability density function $f_Z(z) = \frac{1}{\sqrt{2\pi}\sigma} e^{-\frac{(z-\mu)^2}{2\sigma^2}}$.

Moments: $\mathbb{E}[Z] = \mu$, $\mathbb{E}[Z^2] = \sigma^2 + \mu^2$, $\mathbb{E}[e^Z] = e^{\mu + \frac{1}{2}\sigma^2}$.

Ito's formula

For an Ito process X_t with stochastic differential $dX_t = F_t dt + G_t dB_t$, and a suitably differentiable function $f(t, x)$, it holds that

$$dZ_t = \left\{ \frac{\partial f}{\partial t}(t, X_t) + F_t \frac{\partial f}{\partial x}(t, X_t) + \frac{1}{2} G_t^2 \frac{\partial^2 f}{\partial x^2}(t, X_t) \right\} dt + G_t \frac{\partial f}{\partial x}(t, X_t) dB_t$$

where $Z_t = f(t, X_t)$.

Geometric Brownian motion

For deterministic constants $\alpha, \sigma \in \mathbb{R}$, and $u \in [t, T]$ the solution to the stochastic differential equation $dX_u = \alpha X_u du + \sigma X_u dB_u$ satisfies

$$X_T = X_t e^{(\alpha - \frac{1}{2}\sigma^2)(T-t) + \sigma(B_T - B_t)}.$$

The Feynman-Kac formula

Suppose that $F(t, x)$, for $t \in [0, T]$ and $x \in \mathbb{R}$, satisfies

$$\begin{aligned} \frac{\partial F}{\partial t}(t, x) + \alpha(t, x) \frac{\partial F}{\partial x}(t, x) + \frac{1}{2} \beta(t, x)^2 \frac{\partial^2 F}{\partial x^2}(t, x) - rF(t, x) &= 0 \\ F(T, x) &= \Phi(x). \end{aligned}$$

If X_u satisfies $dX_u = \alpha(u, X_u) du + \beta(u, X_u) dB_u$, then

$$F(t, x) = e^{-r(T-t)} \mathbb{E}_{t,x} [\Phi(X_T)].$$

The Black-Scholes model

The Black-Scholes model is parametrized by the deterministic constants r (continuous interest rate), μ (stock price drift) and σ (stock price volatility).

The value of a unit of cash C_t satisfies $dC_t = rC_t dt$, with initial value $C_0 = 1$.

The value of a unit of stock S_t satisfies $dS_t = \mu S_t dt + \sigma S_t dB_t$, with initial value $S_0 > 0$.

At time $t \in [0, T]$, the price $F(t, S_t)$ of a contingent claim $\Phi(S_T)$ (satisfying $\mathbb{E}^{\mathbb{Q}}[\Phi(S_T)] < \infty$) with exercise date $T > 0$ satisfies the Black-Scholes PDE:

$$\begin{aligned} \frac{\partial F}{\partial t}(t, s) + rs \frac{\partial F}{\partial s}(t, s) + \frac{1}{2} s^2 \sigma^2 \frac{\partial^2 F}{\partial s^2}(t, s) - rF(t, s) &= 0, \\ F(T, s) &= \Phi(s). \end{aligned}$$

The unique solution F satisfies

$$F(t, S_t) = e^{-r(T-t)} \mathbb{E}^{\mathbb{Q}}[\Phi(S_T) | \mathcal{F}_t]$$

for all $t \in [0, T]$. Here, the ‘risk-neutral world’ \mathbb{Q} is the probability measure under which S_t satisfies

$$dS_t = rS_t dt + \sigma S_t dB_t.$$

The Gai-Kapadia model of debt contagion (MAS452/6052 only)

A financial network consists of banks and loans, represented respectively as the vertices V and (directed) edges E of a graph G . An edge from vertex X to vertex Y represents a loan owed by bank X to bank Y .

Each loan has two possible states: healthy, or defaulted. Each bank has two possible states: healthy, or failed. Initially, all banks are assumed to be healthy, and all loans between all banks are assumed to be healthy.

Given a sequence of contagion probabilities $\eta_j \in [0, 1]$, we define a model of debt contagion by assuming that:

- (†) For any bank X , with in-degree j if, at any point, X is healthy and one of the loans owed to X becomes defaulted, then with probability η_j the bank X fails, independently of all else. All loans owed by bank X then become defaulted.

Starting from some set of newly defaulted loans, the assumption (†) is applied iteratively until no more loans default.